SPA – A System for Analysis of Indoor Team Sports Using Video Tracking and Wireless Sensor Network

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Abstract

This paper presents a sport analysis system (SPA – Sport Performance Analyzer), consisting of a high resolution video system together with a wireless sensor network for collecting position data and physiological data of sport players during training or competition. The combination of the two data streams provides a new performance analysis and visualization solution for indoor team sports.

1. Introduction

There is an increasing demand in the sports community to get continuative information of athletes which will support coaches and sport scientists to evaluate the performance of the team as well as the individual players during training and/or official games.

One main task is the tracking of the player positions during a sports event which means finding the position of each player on the play ground in a sufficient accuracy and frequency so that the path information such as distance, speed and acceleration profile can be computed. This information is the basic input for further higher level analysis such as strategy, performance and fitness of the players and helps the coaches to design better training patterns.

The measurement of physiological data of the players is of great importance for the coach and sport scientists because it will show the “internal status” of the players’ bodies during the sports event. Our system provides the possibility to measure the external conditions as well as the internal (physical) strain of the players during their activity. This will provide a new combination of data which is strongly needed by trainers and sport scientists.

In order to obtain the positional information of the players during playing, the game should be recorded using one or more video cameras. The captured video should then be processed either manually or using a computer. As an example of manual analysis of sport videos, in [1] and [2] important information about the load on football players has been obtained. A simple blob tracking of squash players [3] enabled sport researchers to investigate the behavioral features which may determine the looser or the winner in squash matches [4]. The system in [3] has been further developed to track handball players using particle filter and voronoi partitioning as described in [5]. Needham [6] used the so called algorithm CONDENSATION [7] for tracking indoor football players with an accuracy enough to model players behavior. Choi et al. [8] proposed a template matching and Kalman Filter based method to track both the players and the ball in the soccer games using broadcasted TV signal.

The research in the area of measuring physiological data of the players during playing is motivated by the development of small and wearable sensors. Ali and Farrally [9] used short-range radio telemetry sensors which were sampled at 5-s intervals to examine the possibility of obtaining information about the heart rate and physiological load imposed on soccer players during a game. Recently, in [10] a software system has been developed in order to aggregate and visualize the data acquired from a suit of common off-the-shelf body sensors.

We propose a Sport Performance Analyzer (SPA) system that has three main modules, namely data acquisition (Video-System and Wireless Sensor Network), tracking and analysis-visualization as shown in figure 1. The acquisition module is responsible for recording video streams from two cameras and biosignal data. The recording of video and physiological data streams is synchronized to make further analysis of the data easier. Because the amount of physiological data is much less compared to the video data it can be processed and visualized online. For example during the sports event the heart rate can be monitored and the trainer can decide to substitute a player based on his heart rate profile.

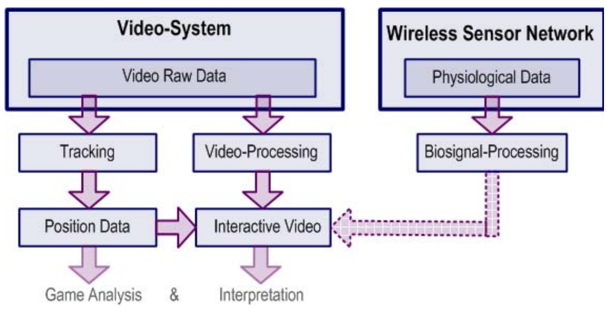


Figure 1: Developed system structure

The video tracking module works offline to provide the position data of the players. It takes as input two video data streams and produces the positions of the players in real world coordinates (meters) which can be processed to gain further information. The analysis & visualization module takes three inputs; video, physiological and position data. It produces different visualizations such as graphs and (interactive) video with annotated information.

2. Wireless Sensor Network

A wireless sensor network is used to collect physiological data (heart rate with optionally skin temperature/conductance) of each athlete in real time. The system constraints include: the data collecting occurs in an indoor environment with the size of at least 40m x 20m, the number of athletes whose data can be collected in parallel is up to 30, the sensor node is sufficiently compact to be worn by the athlete and the battery life time of each sensor node is at least 24 hours of use. Finally, a proper quality of service, e.g. less than 10% packet loss for each sensor node, should be met so that the continuity of data for each athlete is guaranteed.

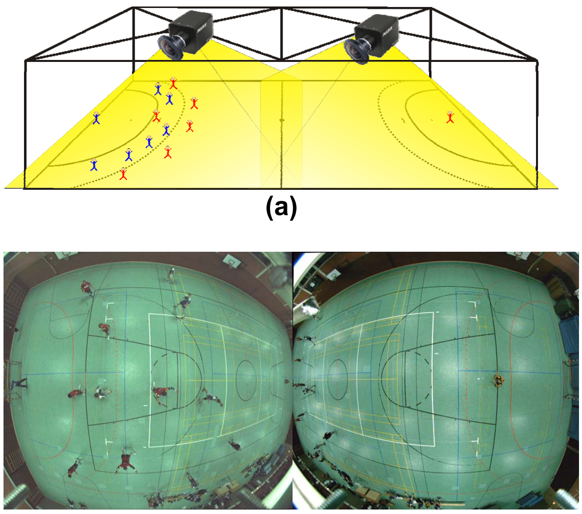
We have applied the shirt-integrated electrodes for our heart rate sensor node (HRSN). The generated signals must be first digitalized and then processed by respective algorithms to output the intended features (physiological data). Our sensor node is composed of a sensor signal processing module and a radio transmission module. The former includes the analog pre-processing circuits, a MCU (Micro Controller Unit) with the A/D converting function and the software for the signal processing algorithm running on the MCU. This module can optionally output two kinds of data to be transmitted, the calculated feature or the original but digitalized sensor signal. The latter module is composed of a radio frequency (RF) transceiver and a dedicated MCU for running the software.

The key task of the wireless sensor network is to transmit the measured data to a central station. Bluetooth is the first candidate to consider as it is widely applied as a cable replacement solution. However, its small network capacity, up to 3sec activation time and high power consumption prevent it to be the appropriate technology for our application. Compared to Bluetooth, ZigBee sacrifices some performance on data rate and reliability to save hardware complexity and power consumption. Furthermore, it also brings the advantages of short activation time (15ms) and large networking capacity. Unfortunately, our implemented prototype shows that even with the simplest operation mode, a general coin cell (CR2032) is not suitable for the peak power requirements of the HRSN (90mW). Applying two coin cells makes the resulting HRSN beyond the prescribed size constraint.

Based on the above trials on Bluetooth and ZigBee, we have sensed that the peak power consumption is the most critical problem that we must deal with. A new technology called ANT [11] comes into our sight. ANT is advocated by Dynastream Innovation Inc. which is actually a specification covering the physical (PHY) layer, media access control (MAC) layer and the networking layer. As our application only requires a multipoint-to-point (also called star) topology, we decided to use our own software instead of ANT-specified MAC & routing software to further reduce the peak/average power consumption. Together with the selected MCU that controls the RF-Chip (nRF24L01, an ANT-compatible RF transceiver from Nordic Semiconductor), the peak power consumed for transmission is about 35mW (11.67mA @ 3V) and the power consumed during the sleep mode is about 21µW.

3. Video-System

In order to keep the tracked players in the field of view all the time during the game two stationary digital cameras have been installed in the sport hall, one over the middle of each half of the field. A fisheye objective is used in order to capture the required view on the image sensor. The selection of the two cameras and the objectives has been done after careful analysis and testing many kinds of cameras with different sensors and objectives.



(a)

(b)

Figure 2. (a) Camera positioning, (b) obtained images from the two cameras installed in University Sport hall of Paderborn.

The two cameras have a Bayer CCD sensor with two fisheye objectives. Each camera has a Gigabit Ethernet interface and is capable of delivering up to 30 fps (frames per second) with a maximum resolution of 1932 x 1040. Figure 2 shows the positioning of the two cameras and the obtained images. Each camera covers also a part the adjoining field. This overlap is used for the later described tracking module (section 4) for the case that a player is crossing from one half of the field to the other.

4. Tracking module

In physical and tactical analysis of indoor team sports, path information of the players is of great importance. In order to acquire players' path information, a training session or game is captured by a video system consisting of two cameras which are placed at the hall ceiling. The video data are post-processed in order to identify positions of the players and to track all players on the field by means of an enhanced template matching algorithm.

In this section we will describe the tracking method used in our system. The required preprocessing and the basic algorithm are presented in sections 4.1 and 4.2, respectively. The management of multiple trackers is presented in section 4.3.

4.1 Background Detection

Background estimation and subtraction is a basic operation in computer vision in which each pixel in the current scene is classified as background or foreground so that the focus of processing will be on the foreground objects. In order to do this segmentation a model of the background should be computed or obtained. This can be done by saving a frame of an empty field. Because the lighting condition may change the estimation of the background may require updating during analysis. A solution to this problem is to compute a background model during or before starting the analysis process and to allow updating the model during the analysis if needed.

In the proposed tracking system we allow the use of previously saved empty background image. It can also be built a background model from several successive frames before the start of the tracking process.

4.2 Tracking algorithm: Template Matching

Template matching [12] is used to find the parts of an image which match with a reference (template image). The template image is compared to all parts of the searched image and a measure of similarity is computed in each comparison step. The position with the highest value of similarity is the possible position of the template in the searched image.

Due to the highly dynamic nature of sport players' movements, the use of a static template is not optimal. The use of a large number of templates is not possible either, because there are many potential orientations for each player with respect to the viewing angle; therefore a dynamic template is used. The template has to be selected by the user before the tracking. When the position with a maximum similarity in the next frame is found it is taken as the template for the following frame and so on. One pre-assumption of this update procedure is a small change in the shape of the tracked object between two successive frames. With higher frame rate the change between two successive frames will be very small. In our implementation the frame rate is 30 fps which gives good results.

If errors occur in the tracking a graphical user interface is also available in order to allow the user to interact manually with the tracking system for error correction.

After some experiments we decided to track the player's head plus part of the shoulder because it's clearly visible and easier to track than the whole body of the player. At the beginning of the tracking process the background model is computed using some frames which contain movements or an empty background as described in section 4.1. After this the user has to select a player to track by marking the player's head, which means initialization of the template for this player. The size of the template is based on the camera resolution, the height of the camera, the used objective and the size of the playing field. In our implementation we have used a template size of 20x20 pixels. Figure 3 shows the selection of the initial template for one player. In the next frame the template is searched as described in section 4.3 in a neighborhood of 100x100 pixels centered on the initial position of the player. The size of this region is based on the image resolution and the maximum speed of the player during a sprint.

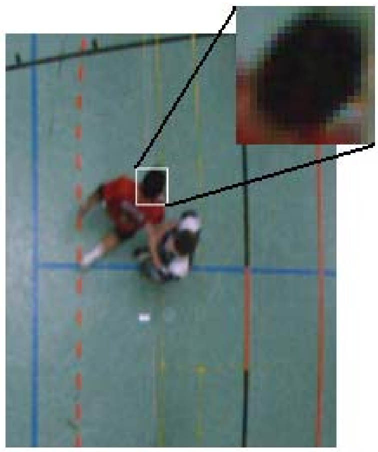


Figure 3. The selection of initial template for tracking a player in a handball game.

4.3 Managing Multiple Trackers

To successfully track multiple players, the information available from each single tracker is used to avoid confusion caused by interaction between players. This is done by assuming that at a given time-step two players can not occupy the same position. To make things more clear we assume that we track N players and at a given point of time the position of each player is known. It is possible to partition the image into N disjoint regions such that each region will contain only one player. Such kind of portioning is called Voronoi partitioning. In our system we have used the implementation of Map Manager Library [13].

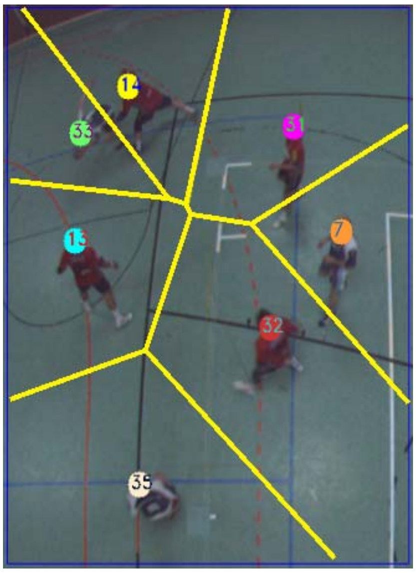


Figure 4. The Voronoi Partitioning used in multiple tracking

Figure 4 shows an example of Voronoi portioning in our system during multiple player tracking in a handball game. This partitioning is used to create a mask for each of the single trackers to be used in avoiding confusion for the case that two or more players interact very closely. These masks are only created for players who are very close to each other based on certain threshold.

5. Visualization of videometrical and physiological data

Video based visualizations can be much more informative than just presenting the results in tabular or graphical form. In order to make it easy to understand the tracking information we have developed an interactive video visualization tool [14] to present the tracking information. This tool allows the user to interactively choose the information that he likes to have visualized in the video (figure 5).

Figure 5. Interactive Visualization Tool

Figure 6 and 7 illustrate the speed diagram and the field coverage of one handball player. The speed diagram shows the percentage of standing, walking, jogging, running and sprinting of the player in a certain playing time, which is very interesting for the users of our system (sport trainers, sport medicine specialists and sport science researchers) in evaluating the performance of the player with respect to the fitness. Field coverage shows the whole path (or part of it) of the player during the game which can be very useful in evaluating the strategic performance of the player.

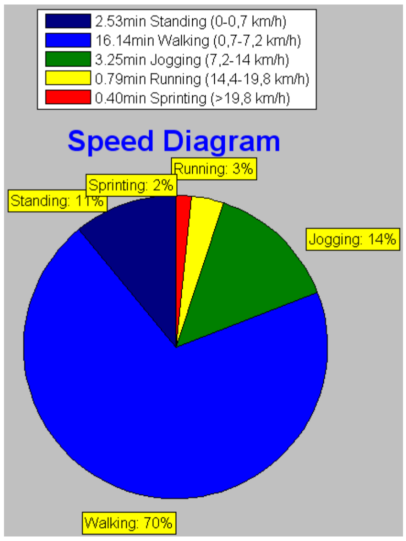


Figure 6. Speed profile of a handball player

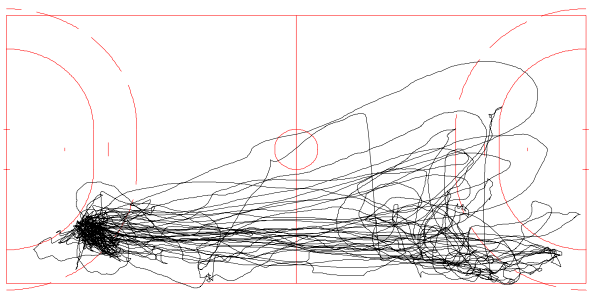


Figure 7. Field Coverage of a handball player

6. Results

Our developed HRSN can transmit every individual heart rate so that a beat-to-beat analysis becomes possible. For a general use[1] the battery lifetime can achieve more than one year (for a 220mAh CR2032) for the communication module.

Regarding the video system, the processing time without correction (f_{auto}) for the szenario of tracking 5 players (*NoP*) is 10fp*s*. The average number of corrections (*cR*) is 0.004 corrections/frame/player. The average correction time (*cT*) for one error is 3.3sec/correction. Finally the frame rate including correction (f_{corr}) is 6 fps.

$$f_{corr} = \frac{1}{\frac{1}{f_{auto}} + cT \cdot cR \cdot NoP} \quad \textbf{(1)}$$

Compared to the source frame rate of the video (30fps), the processing time is 5 times longer than the gross playing time.

By combining the two streams of video and physiological data, we can correlate the instantaneous body conditions with the corresponding game situation based on the performance analysis of each player. With these data, an individualized training plan for every player can be generated. Furthermore, the resulting tactical analysis on the previous games is very helpful to improve strategies for the future trainings and games.

One application of our system is the evaluation of the covered distance in handball and basketball games to generate an individual profile for each player.

7. Discussion

For the first time it is possible to visualize the actual performance profiles for the players of indoor ball games in training or competition and to apply this knowledge to obtain the optimum training pattern and game strategy.

As an enhancement for the sensor network we apply receiver diversity technology for better energy-efficiency and communication reliability, respectively. Our system also provides large flexibility for further designs/improvements, e.g. different heart beat algorithms (QRS Detection) can be implemented on the MCU, the potential to increase the network capacity by a synchronized protocol and the possibility to reduce the packet loss by the acknowledgement & retransmission measure.

In the video tracking system template update presents a problem which is the small drifting of the template out of the tracked part. To overcome this problem and to reduce the number of corrections we are enhancing the tracking by making use of color information.

[1] Provided that each packet requires 300µs to be transmitted (32Bytes@1Mbit/s) and the packet rate is 5Hz.

8. References

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